New Hampshire
Estuaries Project

Environmental Indicator Report

SHELLFISH

Final

September 27, 2002

Prepared by:

Phil Trowbridge
NHEP Coastal Scientist
New Hampshire Department of Environmental Services

This document was funded in part by the U.S. Environmental Protection Agency through a cooperative agreement with the New Hampshire Estuaries Project.

ACKNOWLEDGMENTS

This report was peer-reviewed by the NHEP Technical Advisory Committee. The members of this committee deserve thanks for their time and thoughtful input.

NHEP Technical Advisory Committee

Name	Organization
Steve Jones, Chair	UNH-JEL
Tom Ballestero	UNH
Gregg Comstock	NHDES
Paul Currier	NHDES
Ted Diers	OSP-NHCP
Jennifer Hunter	OSP-NHEP
Natalie Landry	NHDES
Richard Langan	UNH-CICEET
Stephen Mirick	ASNH
Chris Nash	NHDES
Chris Neefus	UNH
Fay Rubin	UNH-CSRC
Fred Short	UNH-JEL
Brian Smith	NHF&G
Sally Soule	OSP-NHCP

Special thanks should also be given to Paul Geoghegan of Normandeau Associates, Ron Sher of Seabrook Station, Bruce Smith of NHF&G, and Brian Beal of University of Maine and Machias for providing data and advice on the shellfish indicators.

INTRODUCTION

During the fall and winter of 2001-2002, the New Hampshire Estuaries Project's Technical Advisory Committee (TAC) developed a suite of environmental indicators to track progress toward the NHEP's management goals and objectives. These indicators were fully described in terms of their performance criteria, statistical methods, and measurable goals in the NHEP's Monitoring Plan published in May 2002.

The next step is to use these indicators to produce an updated "State of the Estuaries" report by the spring of 2003. The TAC decided to break this task into three sections: shellfish indicators in the fall of 2002; water quality indicators in the winter of 2002-2003; and land use/habitat indicators in the spring of 2003. For each group of indicators, the NHEP Coastal Scientist would prepare an "Indicator Report" that summarizes the available information and results of statistical tests for each of the indicators. The TAC would review and comment on this report, and then recommend a subset of the most important or illustrative indicators to be presented to the Management Committee. Finally, after being presented to both the TAC and the Management Committee, the indicator charts and interpretation would be incorporated in the State of the Estuaries report.

This report is the first of three indicator reports that will be presented to the TAC over the next six months. The focus of this report is the NHEP's shellfish resource indicators (see list below). In an effort to be brief, the details of the monitoring programs for each indicator are not included. Please refer to the NHEP Monitoring Plan for additional details for each indicator.

List of NHEP Shellfish Indicators

SHL1 – Area of Oyster Beds in Great Bay
SHL2 – Density of Harvestable Oysters at Great Bay Beds
SHL3 – Density of Harvestable Clams at Hampton Harbor Flats
SHL4 – Area of Clam Flats in Hampton Harbor
SHL5 – Standing Stock of Harvestable Oysters in Great Bay
SHL6 – Standing Stock of Harvestable Clams in Hampton Harbor
SHL7 – Abundance of Shellfish Predators
SHL8 – Clam and Oyster Spatfall
SHL9 – Recreational Harvest of Oysters
SHL10 – Recreational Harvest of Clams
SHL11 – Prevalence of Oyster Disease
SHL12 – Prevalence of Clam Disease

ENVIRONMENTAL INDICATORS

SHL1. Area of Oyster Beds in Great Bay

a. Monitoring Objectives

The objective of this indicator is to track the area of the six major oyster beds in Great Bay relative to their areas in 1997. This is directly relevant to the following management objective:

- SHL1-3: No net decrease in acreage of oyster beds from 1997 amounts for Nannie's Island, Woodman Point, Piscataqua River, Adams Point, Oyster River, Squamscott River, and Bellamy River beds

b. Measurable Goal

The goal is for each bed to at least maintain its 1997 area as reported in Langan (1997):

Oyster Bed	Size in 1997 (acres)
Nannie Island	6.6
Woodman Point	37.3
Piscataqua River	12.8
Adams Point	4.0
Oyster River	1.8
Squamscott River	1.7

Note: The TAC decided that it was not worthwhile to track the size of the oyster bed in the Bellamy River because of its small size even though it was included in the management objective above.

c. Data Analysis and Statistical Methods

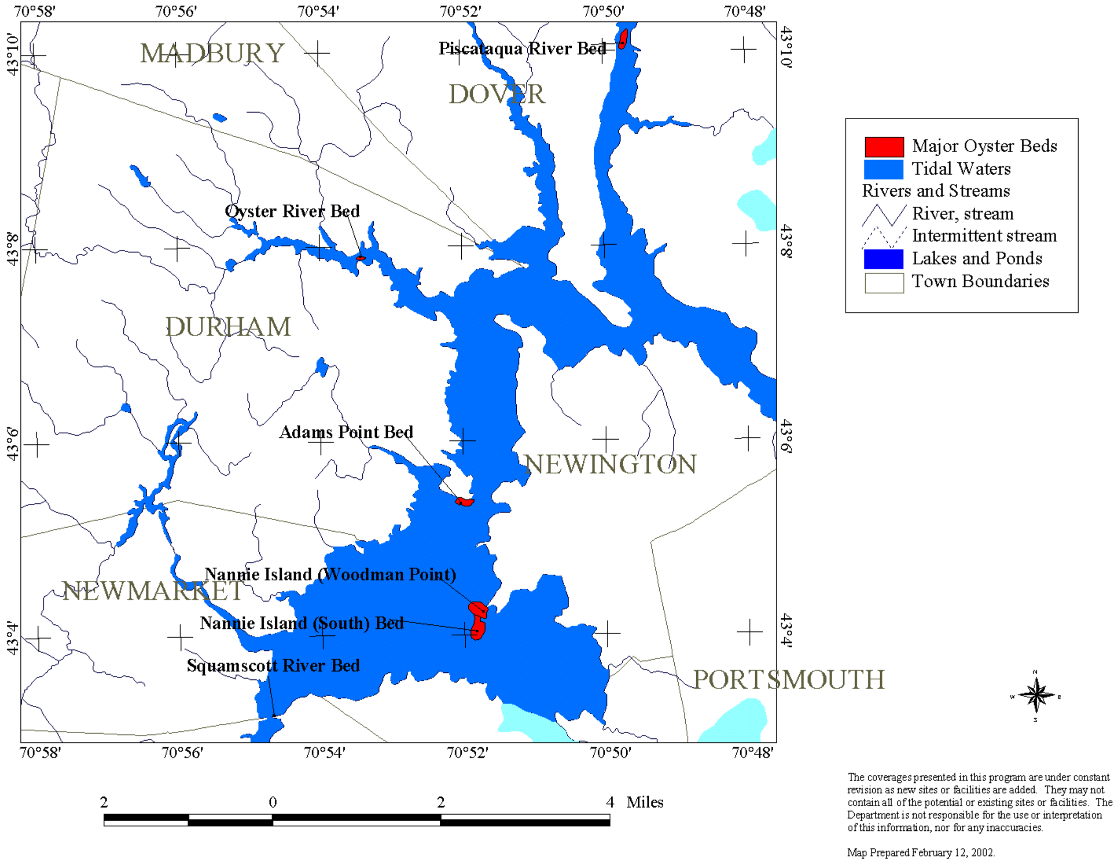
A rigorous statistical test to test for differences between 1997 and subsequent oyster bed areas is not possible. Instead, the error bars for the area estimate will be used to establish an approximate "confidence interval" of possible values for the estimate.

d. Results

The oyster beds have not been mapped since 1997 so comparisons to 1997 sizes are not possible. NHF&G and UNH, with partial support from NHEP, will complete a new set of maps of the oyster beds by the end of 2002.

The general locations of the six oyster beds that are being tracked by the NHEP are shown in the following figure from the Monitoring Plan.

Figure 5-1: Major Oyster Beds in Great Bay.



SHL2. Density of Harvestable Oysters at Great Bay Beds

a. Monitoring Objectives

The objective of this indicator is to estimate the average density of harvestable oysters at the six major oyster beds in Great Bay. This indicator reports directly on the following management objective:

- SHL1-4a: No net decrease in oysters (≥80 mm shell height) per square meter from 1997 amounts at Nannie's Island, Woodman Point, Piscataqua River, Adams Point, and Oyster River.

b. Measurable Goal

The goal is for each bed to maintain its 1997 density (for oysters ≥80mm shell height).

c. Data Analysis and Statistical Methods

For each bed, the arithmetic mean and standard deviation of the number of oysters ≥80mm shell height per quadrat will be calculated. A one-sample, two-sided t-test with an alpha level of 0.05 will be used to determine whether the densities are significantly different from the goals (1997 levels).

d. Results

Oysters have suffered a significant decline in recent years. The following table and figures illustrate that densities are well below the NHEP goal of 1997 levels (statistically significant difference). The cause for this decline has been mainly attributed to the protozoan pathogens MSX and DERMO. On average, the harvestable oyster densities are approximately 25% of the management goal (1997 levels).

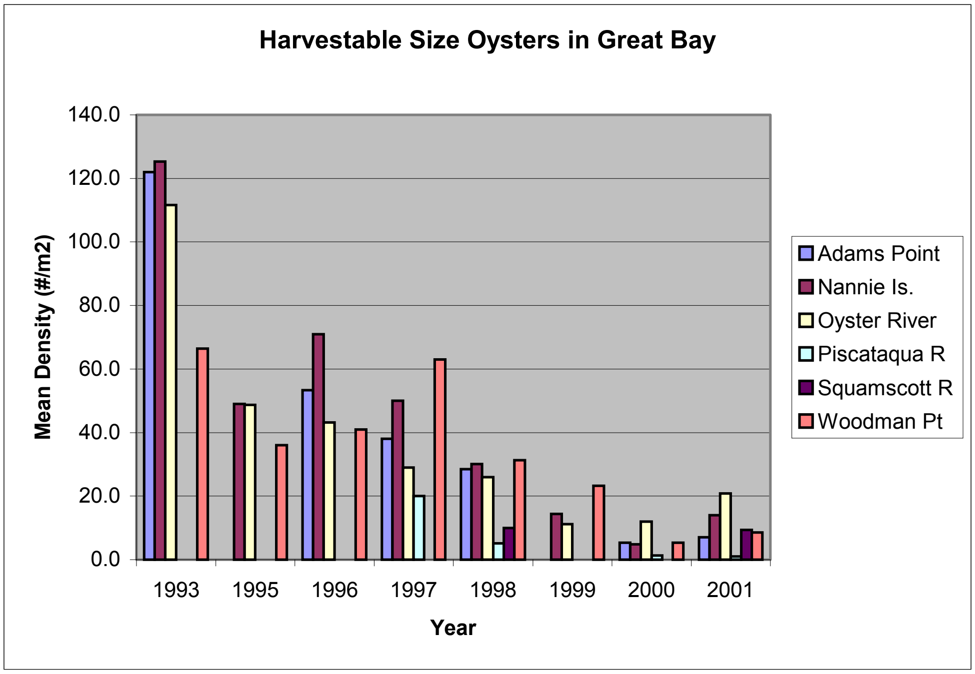
Arithmetic Mean Density of Harvestable (≥80mm shell height) Oysters at Great Bay Beds (#/m^2)

Year	Adams Point	Nannie Island	Oyster River	Piscataqua River	Squamscott River	Woodman Point	Source
1993	122.0	125.3	111.6			66.4*	NHF&G
1995		49.0	48.7			36.0	NHF&G
1996	53.3	71.0	43.2			41.0	NHF&G
1997	38.0	50.0	29.0	20.0		63.0	Langan (1997)
1998	28.5	30.1	26.0	5.1	10.0	31.3	NHF&G
1999		14.4	11.2	0.0		23.2	NHF&G
2000	5.3	4.8	12.0	1.3		5.3	NHF&G
2001	7.0	14.0	20.8	1.0	9.3	8.6	NHF&G

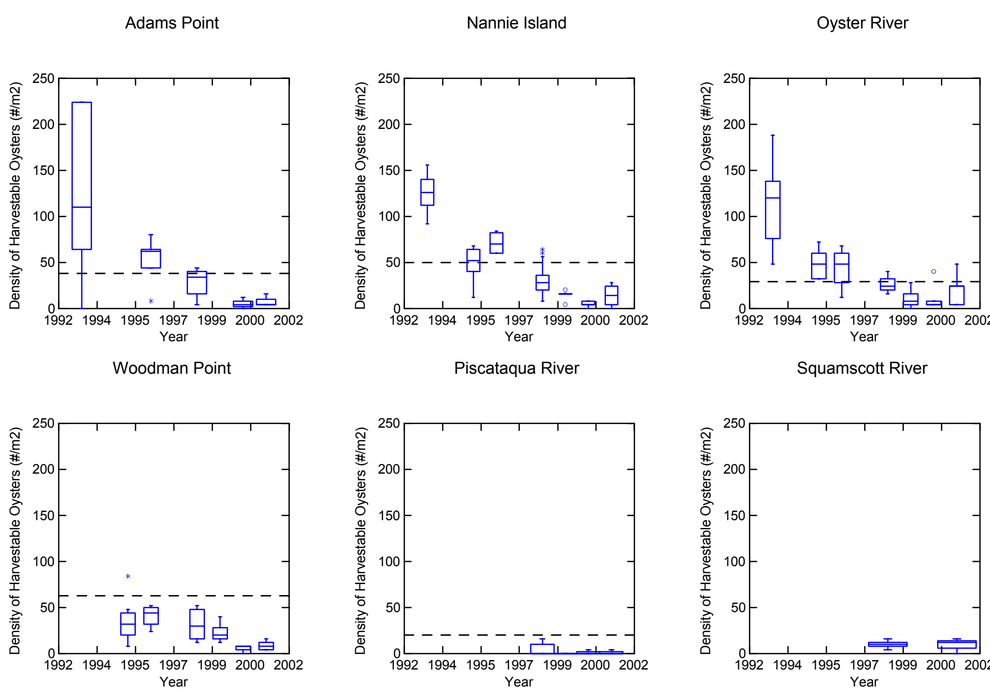
Green cells are the Management Goals for harvestable oyster density from Langan (1997)

Yellow cells are statistically significant ($p<0.05$) decreases below management goals using a one sample, two-sided t-test.

* Value from NHF&G reports. Raw data for individual quadrats not available for boxplot and statistical significance analysis.



The following figure illustrates the variance in harvestable oyster density at the six major beds over time. The data source for this graph is the NHF&G Oyster Resource Database. Data from Langan (1997) are not included in this figure, although the mean densities from 1997 are indicated by dashed lines.



Note: To read this box plot, the bottom, middle, and top of the box indicate the 25th, 50th, and 75th percentiles, respectively. The lines extending from the box reach as far as the 5th and 95th percentiles. Points beyond the box and lines are outlier values.

SHL3. Density of Harvestable Clams at Hampton Harbor Flats

a. Monitoring Objectives

The objective of this indicator is to estimate the mean density of clams of harvestable size (≥50mm) from the NH's major clam flats in Hampton Harbor. This indicator will report directly on the following management objective:

- SHL1-4b: No net decrease in adult clams (≥50 mm shell length) per square meter from the 1989-1999 10-year average at Common Island, Middle Ground, and Confluence flats.

b. Measurable Goal

The goal is for each flat to at least maintain the 10-year average density for clams of harvestable size (≥50mm shell length).

Arithmetic Mean Density of Harvestable Size Clams

Flat	10 year Average (1990-1999)
Common Island	22.0 #/m2
Hampton-Browns Confluence	10.8 #/m2
Middle Ground	37.2 #/m2

c. Data Analysis and Statistical Methods

For each flat, the arithmetic mean of the number of clams ≥50mm per quadrat will be calculated. Ultimately, a one-sample t-test with an alpha level of 0.05 will be used to determine whether the densities are significantly different from the goal. However, information on the variance in density between quadrats is not currently available, therefore only the mean density will be reported for this analysis. The mean density values will be compared to the goal.

d. Results

The following table and figure illustrate trends in harvestable clam populations over the last 30 years. The densities have followed a cyclical pattern with a period of approximately 12 years. For instance, at Common Island, peak densities between 35.5 and 61.0 #/m2 were observed in 1972, 1983, and 1997. Between these peaks, the harvestable clam density fell to 1-2 #/m2. Densities in 2000 are less than average and falling.

The Management Goal is the 10-year average between 1990 and 1999. During this period, the clam densities grew to unprecedented levels, due in part to the clam flats being closed for harvest in the early 1990s. To capture the effects of the growth and decline cycles, a more suitable period for comparison would be the period between the two crashes in 1977 and 1987. The average density values for this period are:

Arithmetic Mean Density of Harvestable Size Clams

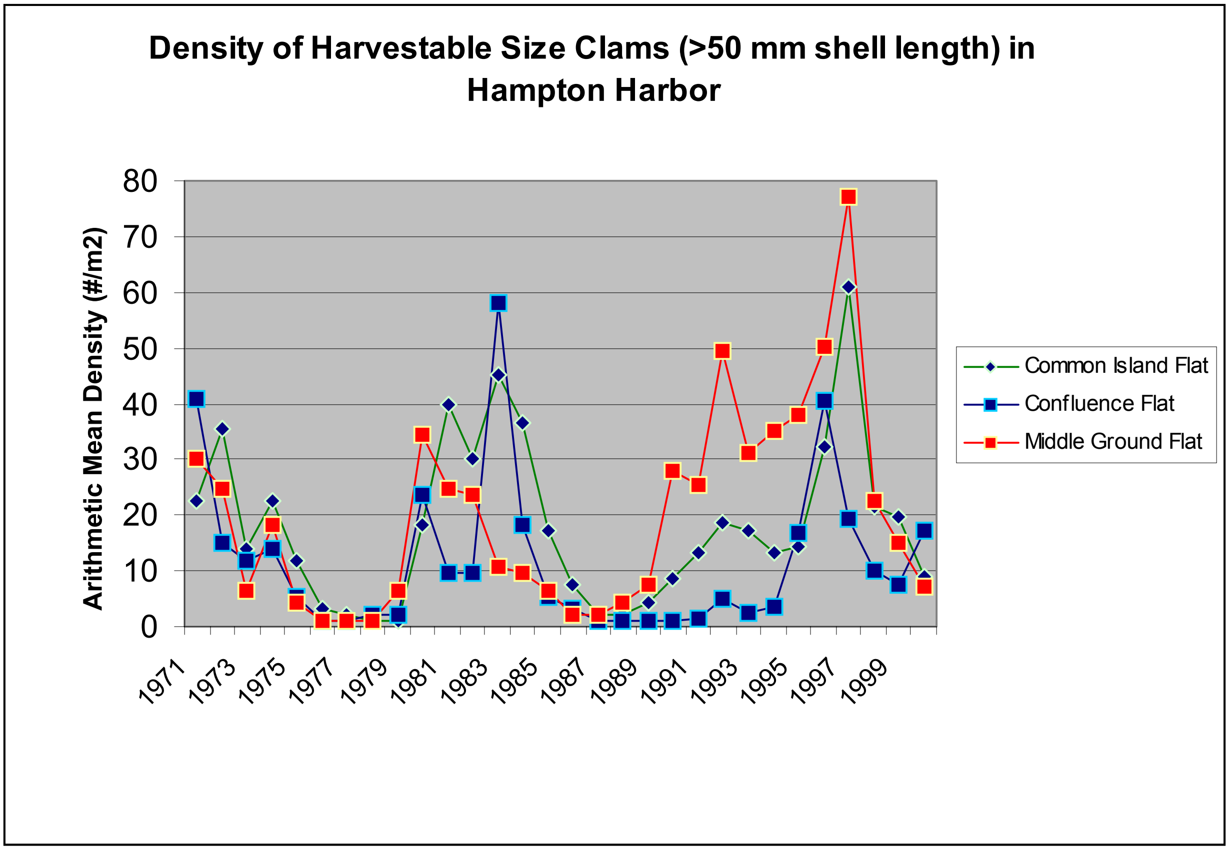
Flat	11 year Average (1977-1987)
Common Island	18.3 #/m2
Hampton-Browns Confluence	12.2 #/m2
Middle Ground	11.2 #/m2

The average values for this period are not very different from the 1990-1999 period for the Common Island and Conflucence flats. However, there is a big difference for the Middle Ground flat.

Arithmetic Mean Density of Harvestable Size Clams in Hampton Harbor (#/m2)

Year	Common Island Flat	Confluence Flat	Middle Ground Flat	Source
1971	22.6	40.9	30.1	Seabrook Station
1972	35.5	15.1	24.8	Seabrook Station
1973	14.0	11.8	6.5	Seabrook Station
1974	22.6	14.0	18.3	Seabrook Station
1975	11.8	5.4	4.3	Seabrook Station
1976	3.2	1.1	1.1	Seabrook Station
1977	2.2	1.1	1.1	Seabrook Station
1978	1.1	2.2	1.1	Seabrook Station
1979	1.1	2.2	6.5	Seabrook Station
1980	18.3	23.7	34.4	Seabrook Station
1981	39.8	9.7	24.8	Seabrook Station
1982	30.1	9.7	23.7	Seabrook Station
1983	45.2	58.1	10.8	Seabrook Station
1984	36.6	18.3	9.7	Seabrook Station
1985	17.2	5.4	6.5	Seabrook Station
1986	7.5	3.2	2.2	Seabrook Station
1987	2.2	1.1	2.2	Seabrook Station
1988	2.2	1.1	4.3	Seabrook Station
1989	4.3	1.1	7.5	Seabrook Station
1990	8.6	1.1	27.9	Seabrook Station
1991	13.4	1.6	25.6	Seabrook Station
1992	18.5	4.9	49.5	Seabrook Station
1993	17.1	2.7	31.1	Seabrook Station
1994	13.2	3.6	35.3	Seabrook Station
1995	14.3	16.8	37.9	Seabrook Station
1996	32.3	40.7	50.1	Seabrook Station
1997	61.1	19.4	77.2	Seabrook Station
1998	21.6	10.2	22.5	Seabrook Station
1999	19.7	7.4	15.0	Seabrook Station
2000	9.0	17.3	7.3	Seabrook Station

Shaded cells are less than the management goal for that flat. No tests of statistical significance could be performed.



Density of Harvestable Size Clams (>50 mm shell length) in Hampton Harbor
Arithmetic Mean Density (#/m2)
80
70
60
50
40
30
20
10
0
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Common Island Flat
Confluence Flat
Middle Ground Flat

SHL4. Area of Clam Flats in Hampton Harbor

a. Monitoring Objectives

The objective of this supporting variable is to track the size of the three major clam flats in Hampton Harbor. This information will be combined with data on clam densities to estimate the standing stock of harvestable clams for another indicator.

b. Measurable Goal and Statistical Methods

This is a supporting variable so no measurable goal has been established.

c. Data Analysis and Statistical Methods

These data will be collected to provide additional information to help interpret the results of other indicators. The area of each flat will be reported along with the error in the estimate. No statistical tests will be applied.

d. Results

The following table and figure show the area of the three major clam flats mapped during 6 surveys. There are no apparent system-wide trends. The Common Island and Middle Ground flats showed a decrease in bed size, while the Confluence flat showed a slight increase in bed size. The latest available data on flat areas is from 1995. Seabrook Station plans to map the clam flats again during 2002. The general location of these three major flats is shown in the second figure from the Monitoring Plan.

Area of Major Clam Flats in Hampton Harbor (acres)

Flat	1977	1979	1981	1983	1984	1995	Source
Common Island Flat	54.9	54.8	54	52.7	50	45.7	Seabrook Stn
Confluence Flat	27.2	26.7	24.7	26.4	21.7	26.4	Seabrook Stn
Middle Ground Flat	49.7	53.5	50.8	49.9	47.9	47.3	Seabrook Stn

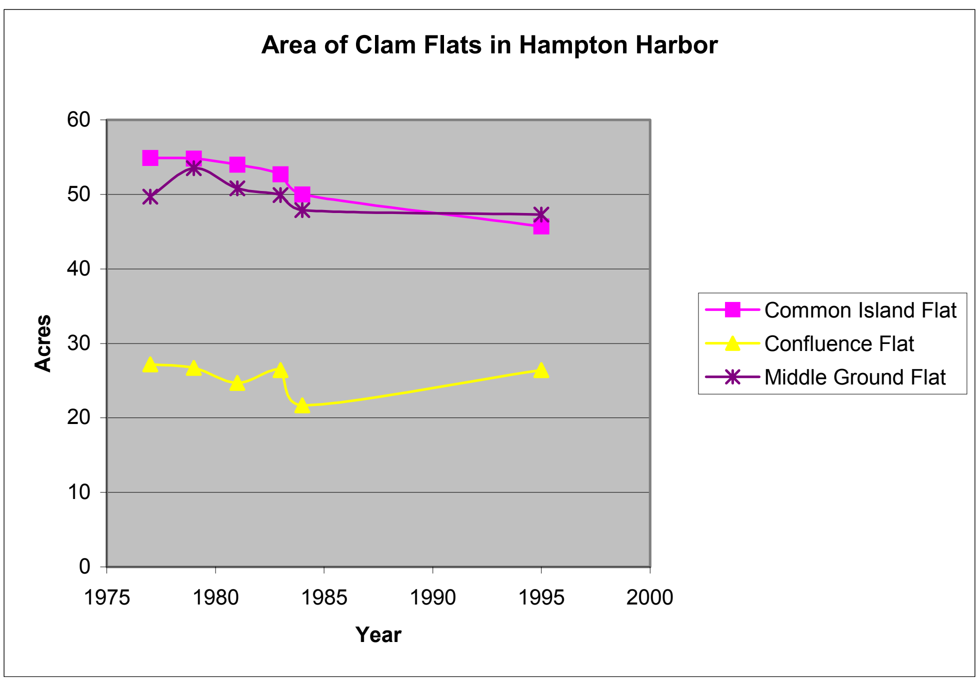
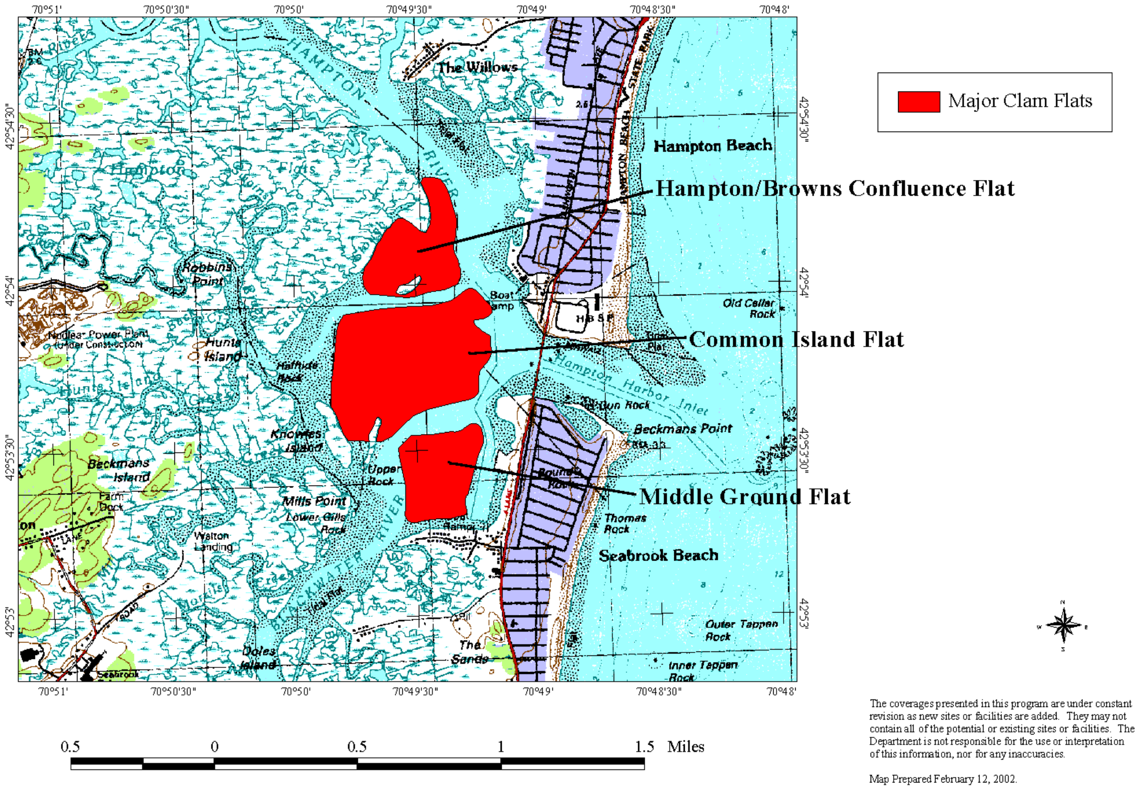


Figure 5-2: Major Clam Flats in Hampton Harbor.



SHL5. Standing Stock of Harvestable Oysters in Great Bay

a. Monitoring Objectives

The objective of this indicator is to estimate the total number of harvestable oysters in Great Bay (i.e., oyster of harvestable size in beds that are open for harvesting). This indicator will answer the following monitoring question:

- "Has the number of harvestable clams and oysters tripled from 1999 levels?"

which will, in turn, report on progress towards a component of Shellfish Goal#1 which calls for the quantity of harvestable clams and oysters in NH's estuaries to be tripled.

b. Measurable Goal and Performance Criteria

In the NHEP Management Plan, Shellfish Goal #1 states that the quantity of harvestable clams and oysters in NH's estuaries should be tripled. The TAC has concluded that a more accurate assessment of both density and size for oyster beds is needed before this goal can be adopted. Based on the results of this assessment, the TAC will either confirm that tripling the standing stock of harvestable oysters is a realistic goal or recommend an alternative target consistent with the spirit of the management goal.

c. Data Analysis and Statistical Methods

The standing stock of harvestable oysters in each bed will be estimated by multiplying the average density of oysters >80mm shell height by the most recent estimate of the bed size. Results will be reported in bushels (for Great Bay, approximately 200 oysters equal 1 bushel). If data on density or area are missing for a bed for a particular year, the standing stock will be estimated from the closest other available data for that bed. The standing stock will be summed for beds in areas open for harvesting. A separate standing stock calculation will be made for oysters >80mm in areas that are closed to harvesting. Rigorous statistical tests for differences are not possible.

d. Results

Data from 1993 to present illustrate that the oyster fishery in Great Bay has suffered a serious decline. The 2001 standing stock is approximately 16% of average levels from 1993-1997. Using an cost estimate of $0.45/oyster, the wholesale value of the fishery has dropped from over $8m to $1m. (Note: This cost estimate is hypothetical because there is no commercial oyster harvesting in NH.) The major cause of this decline is thought to be the protozoan pathogens MSX and DERMO which have caused similar declines in oyster fisheries in the Chesapeake and other mid-Atlantic estuaries. Most of the remaining standing stock is in the beds that are open for harvesting.

The Management Goal for oyster standing stock is to triple the quantity of harvestable oysters from 1999 levels. Three times the 1999 total standing stock for open beds (because other beds are not open for harvesting) would be 68,000 bushels. This value is approximately equal to the average standing stock from 1993-1997 for all beds (both open and closed). As illustrated by the figures, the 1993-1997 period appears to precede the effects of significant oyster mortality from MSX and DERMO. Therefore, a standing stock of 68,000 bushels could be possible for the Great Bay if all oyster disease mortality ceased and all estuarine waters were open for shellfish harvesting.

Harvestable Oyster Standing Stock in Great Bay (bushels)

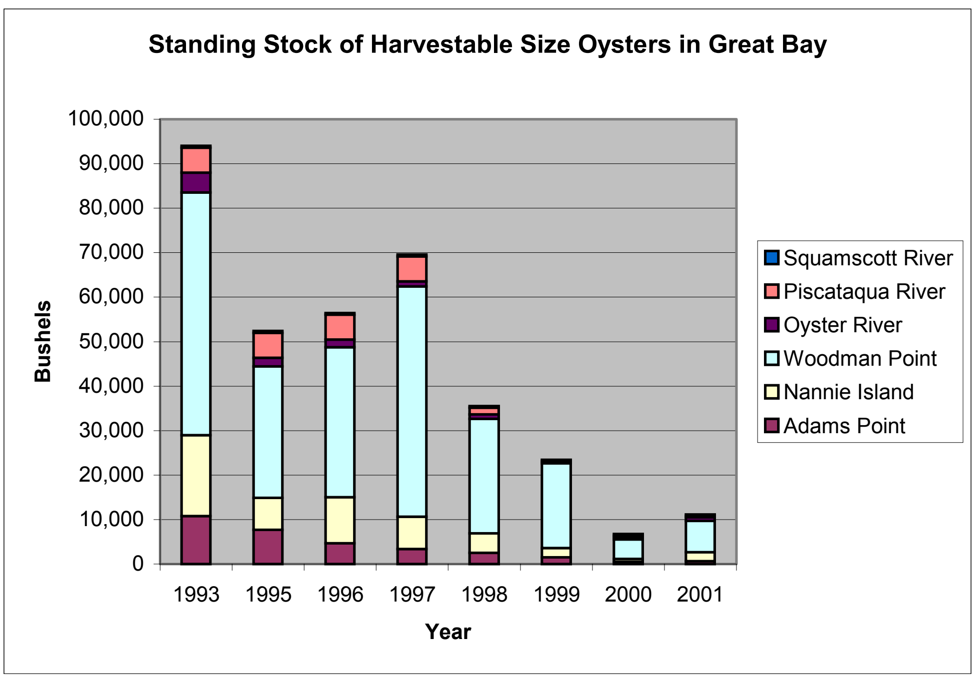
Year	Adams Point	Nannie Island	Woodman Point	Oyster River	Piscataqua River	Squamscott River	Total - open beds	Total – all beds
1993	10,753	18,227	54,575	4,428	5,641	375	83,555	93,998
1995	7,727	7,126	29,589	1,930	5,641	375	44,442	52,387
1996	4,701	10,326	33,698	1,713	5,641	375	48,725	56,454
1997	3,349	7,272	51,780	1,150	5,641	375	62,401	69,567
1998	2,512	4,374	25,753	1,031	1,451	375	32,639	35,495
1999	1,491	2,094	19,068	444	0	362	22,653	23,460
2000	470	698	4,383	476	376	362	5,552	6,766
2001	617	2,036	7,045	825	282	350	9,698	11,155

All values except 1997 are approximate. The only year for which both size and density of the beds were measured was 1997. The size estimates from 1997 were applied to other years in order to estimate the standing stock, but this requires the assumption that the bed sizes have not changed over 5 years, which may not be justified. The average harvestable oyster density for Woodman Point in 1993 was taken from NHF&G reports because raw data were not available to calculated this value independently.

Yellow cells indicate that an assumption regarding the density of oysters was needed to calculate the standing stock because density measurements were not taken at that bed in that year. Either the closest standing stock calculation from another year or an average of two bracketing standing stocks was used.

Sources: Langan (1997) for 1997 values and NHF&G for all other years.

Open beds include Adams Point, Nannie Island, and Woodman Point. Closed beds are: Oyster River, Piscataqua River, and Squamscott River.



SHL6. Standing Stock of Harvestable Clams in Hampton Harbor

a. Monitoring Objectives

The objective of this indicator is to estimate the total number of harvestable clams in Hampton Harbor (i.e., clams of harvestable size in Hampton Harbor flats that are open for harvesting). This indicator will answer the following monitoring question:

- “Has the number of harvestable clams and oysters tripled from 1999 levels?”

which will, in turn, report on progress towards a component of Shellfish Goal#1 which calls for the quantity of harvestable clams and oysters in NH’s estuaries to be tripled.

b. Measurable Goal

In the NHEP Management Plan, Shellfish Goal #1 states that the quantity of harvestable clams and oysters in NH’s estuaries should be tripled. The assumption behind this goal for clams was to maintain the current standing stock in Hampton Harbor, while increasing the overall standing stock by opening other areas of the Hampton/Seabrook and Great Bay estuaries. While this plan may yet work, the TAC has concluded that it would not be cost effective to accurately monitor clam standing stock in the Great Bay Estuary because it is a large area and because the clams are not concentrated in well-defined locations. Without being able to quantify the standing stock throughout the estuaries, it will not be possible to know whether the goal of tripling the resource has been reached.

As an alternative, the TAC has proposed to monitor the standing stock of clams in Hampton Harbor. Hampton Harbor is the main clam resource area in the NH coast and, because of its compact size, it is feasible to monitor the standing stock in this area yearly. However, the TAC does not recommend that the goal of tripling the resource be applied to this indicator at this time. After an analysis of historical data and the potential for new Hampton Harbor flats to be opened for harvest, the TAC will either confirm that the tripling goal is realistic or recommend an alternative target consistent with the spirit of the management goal.

c. Data Analysis and Statistical Methods

Seabrook Station calculates the the standing stock of harvestable clams in Hampton Harbor using the average density for each size clam on the flats (with 1 mm shell length increments for each size class), volume estimates for each size clam from Belding (1930), and the most recent area of each flat. The value of the clam fishery can be estimated by multiplying the standing crop value from Seabrook Station by the extremes of clam wholesale prices: summer ($250/bu) and winter ($50/bu). Please note that the value of the clam fishery is hypothetical because there is no commercial clam harvesting in New Hampshire.

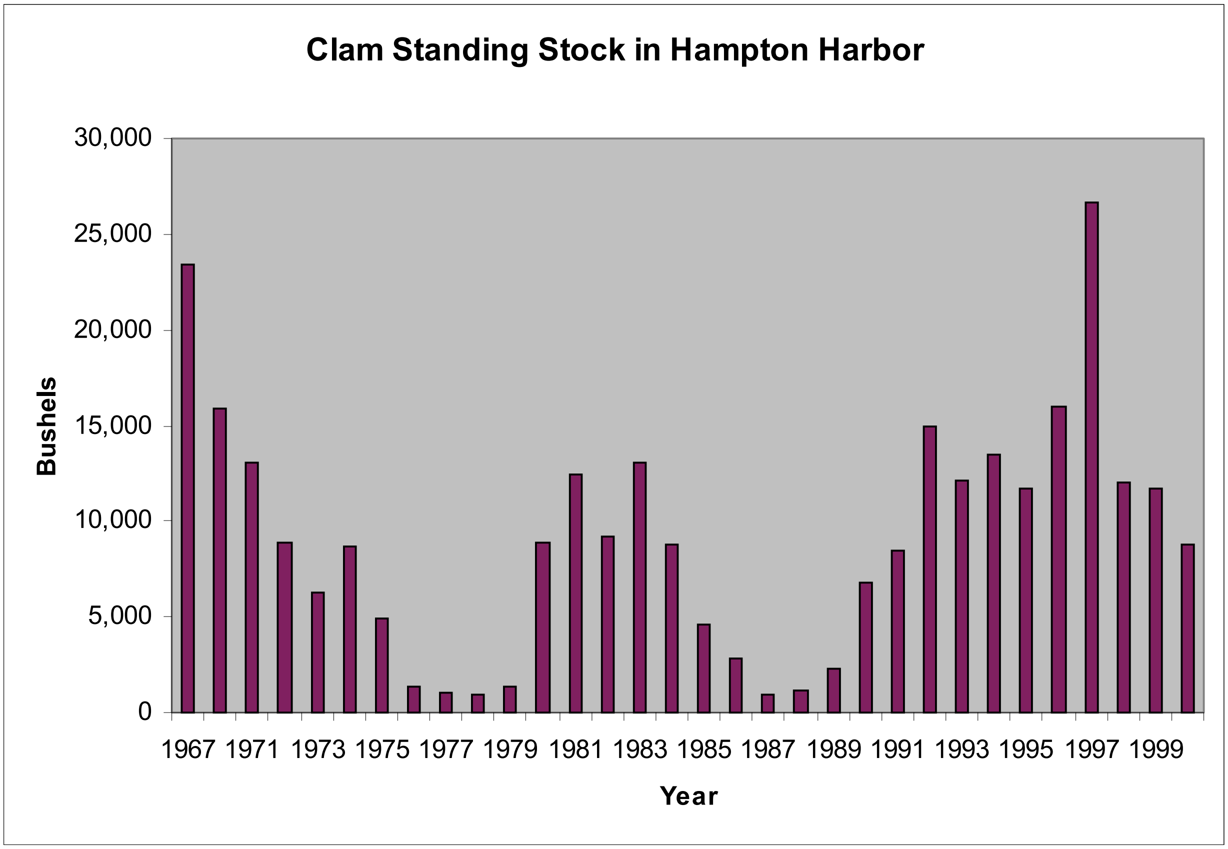
d. Results

The following table and figures show the history of harvestable clam standing stock over the past 30 years. The standing stock has undergone several 12-15 year cycles of growth and decline. Peak standing stocks of approximately 23,000, 13,000, and 27,000 bushels occurred in 1967, 1983,and 1997 respectively. Between the peaks, there have been crashes of the fishery in 1978 and 1987, with standing stock less than 1,000 bushels. Since 1997, the standing stock has been dropping once again but the 2000 levels (the most recent available data) are still approximately ten times the levels observed during the crashes in 1978 and 1987. During the summer season when wholesale prices are approximately $250/bushel, the value of the fishery has been as high as $6.6m. The 2000 value was approximately $2.2m. (Note: This cost estimate is hypothetical because there is no commercial clam harvesting in NH.)

Standing Stock of Harvestable Clams in Hampton Harbor

Year	Standing Stock (bu)	Source
1967	23,400	Seabrook Station
1969	15,840	Seabrook Station
1971	13,020	Seabrook Station
1972	8,920	Seabrook Station
1973	6,310	Seabrook Station
1974	8,690	Seabrook Station
1975	4,945	Seabrook Station
1976	1,350	Seabrook Station
1977*	1,060	Seabrook Station
1978	940	Seabrook Station
1979*	1,400	Seabrook Station
1980	8,890	Seabrook Station
1981*	12,400	Seabrook Station
1982	9,200	Seabrook Station
1983*	13,019	Seabrook Station
1984*	8,821	Seabrook Station
1985	4,615	Seabrook Station
1986	2,793	Seabrook Station
1987	976	Seabrook Station
1988	1,137	Seabrook Station
1989	2,295	Seabrook Station
1990	6,752	Seabrook Station
1991	8,462	Seabrook Station
1992	14,942	Seabrook Station
1993	12,161	Seabrook Station
1994	13,440	Seabrook Station
1995*	11,701	Seabrook Station
1996	16,001	Seabrook Station
1997	26,606	Seabrook Station
1998	11,992	Seabrook Station
1999	11,756	Seabrook Station
2000	8,765	Seabrook Station

* Clam flat maps were made in this year so the standing stock estimate is accurate. All other values are estimates extrapolated using area estimates from the next closest year(s).



Clam Standing Stock in Hampton Harbor
30,000
25,000
20,000
15,000
10,000
5,000
0
Bushels
1967 1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999
Year

SHL7. Abundance of Shellfish Predators

a. Monitoring Objectives

The objective of this supporting variable is to track the relative abundance of the dominant clam predator and incidental oyster predator in NH tidal waters: green crabs (*Carcinus maenus*). This information will be used to help interpret changes in other indicators of shellfish density or standing stock, and will help to answer the following monitoring question:

- "Are NH shellfish healthy, growing, and reproducing at sustainable levels?"

Mud crabs and the oyster drill (*Urosalpinx cinerea*) are more important than green crabs as oyster predators but there are no systematic monitoring programs for these species.

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

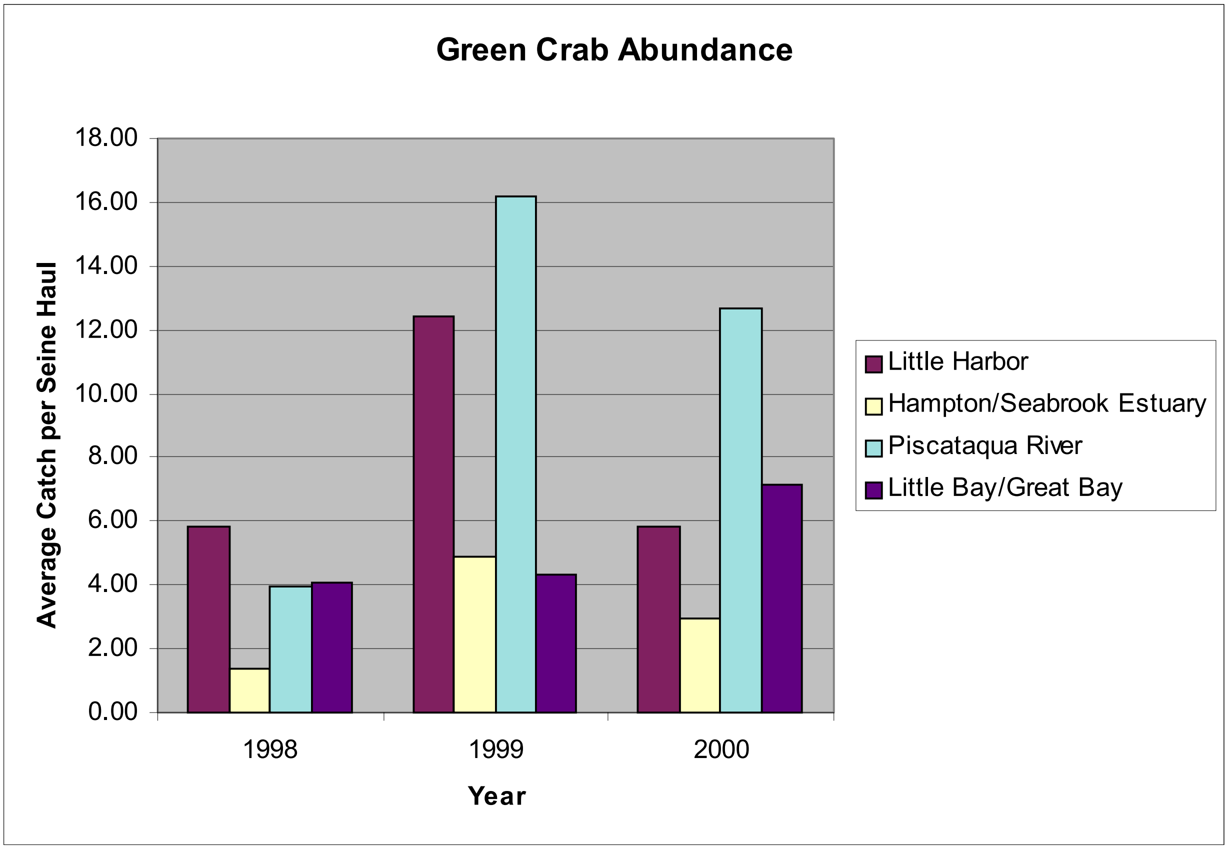
The monthly catch-per-unit-effort (CPUE) of green crabs in various locations throughout the Great Bay and Hampton Harbor will be tracked versus time. No statistical tests will be applied.

d. Results

NHF&G data for the Juvenile Finfish Seine Survey Program from throughout the estuary are shown in the following table and figure. These data are generated by a single seine haul will be made at 15 stations during the months of June through November. These data indicate that green crab abundance is lowest in Hampton Harbor. None of the seine hauls were taken directly from oyster beds so the prevalence of green grabs among the oysters is unknown.

Green Crab CPUE from NHF&G (Annual Average Catch Per Seine Haul)

Location	1998	1999	2000	Source
Little Harbor	5.85	12.39	5.86	NHF&G, Stations 5, 7, 9
Hampton/Seabrook Estuary	1.36	4.92	2.93	NHF&G, Stations 23, 25, 29, 33
Piscataqua River	3.93	16.20	12.67	NHF&G, Stations 30, 35, 39
Little Bay/Great Bay	4.10	4.31	7.12	NHF&G, Stations 54, 72, 93, 107, 147


Green Crab Abundance
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Average Catch per Seine Haul
1998
1999
2000
Year
Little Harbor
Hampton/Seabrook Estuary
Piscataqua River
Little Bay/Great Bay

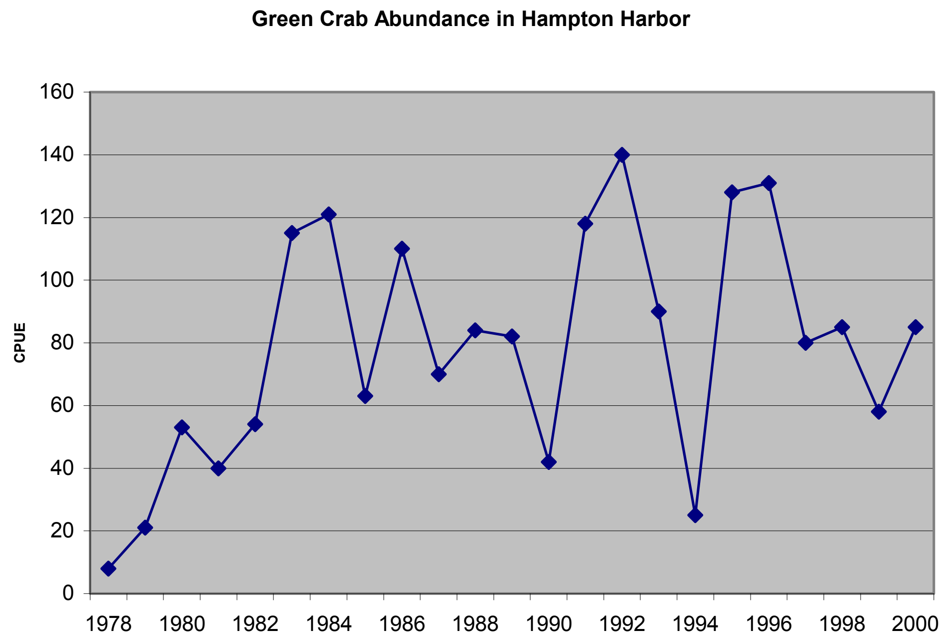
Time series data on green crab abundance in Hampton Harbor monitored by Seabrook Station show an increase in abundance over time. The Mann-Kendall Test indicates that this increase is statistically significant at the $p<0.05$ level with a median increase over the past 20 years of 174% (nearly tripling). These data are generated by green crab traps set at four stations two times per month April through January.

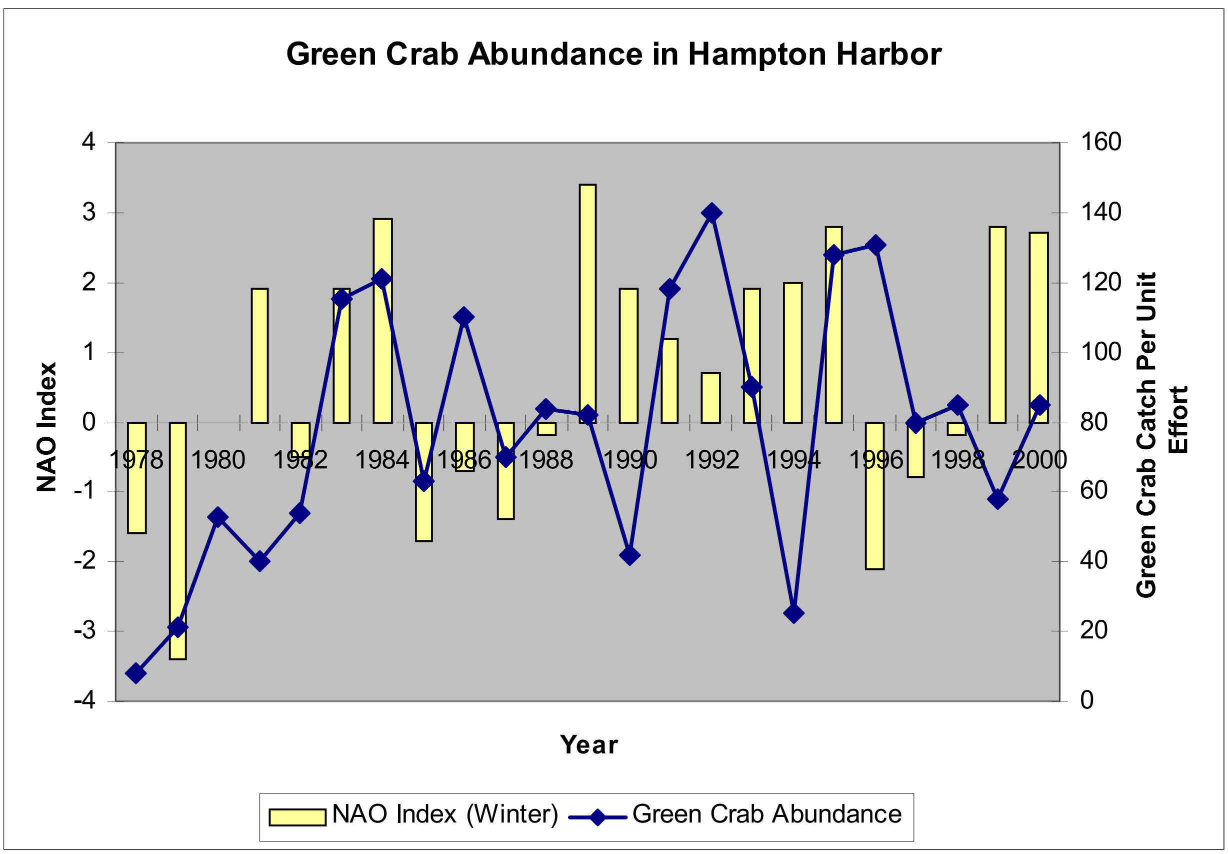
Seabrook Station and others have observed that green crab abundance is correlated with yearly minimum water temperatures (NAESCO, 2001). Temperatures in New England are affected by the North Atlantic Oscillation (NAO) weather pattern. During periods with a negative NAO index, the winters tend to be colder and dryer, which would result in a decrease in the green crab abundance. The second figure below illustrates the relationship between green crab abundance and the NAO winter index.

Abundance of Green Crabs in Hampton Harbor (CPUE)

Year	CPUE	Source
1978	8	Seabrook Station
1979	21	Seabrook Station
1980	53	Seabrook Station
1981	40	Seabrook Station
1982	54	Seabrook Station
1983	115	Seabrook Station
1984	121	Seabrook Station
1985	63	Seabrook Station
1986	110	Seabrook Station
1987	70	Seabrook Station
1988	84	Seabrook Station
1989	82	Seabrook Station
1990	42	Seabrook Station
1991	118	Seabrook Station
1992	140	Seabrook Station
1993	90	Seabrook Station
1994	25	Seabrook Station
1995	128	Seabrook Station
1996	131	Seabrook Station
1997	80	Seabrook Station
1998	85	Seabrook Station
1999	58	Seabrook Station
2000	85	Seabrook Station

Note: values for this table were estimated from graphs in NAI reports because tabular data were not available.





NAO Index Data provided by the Climate Analysis Section, NCAR, Boulder, USA, Hurrell (1995). Seasonal index (December, January, February) of the NAO based on the difference of normalized sea level pressures (SLP) between Ponta Delgada, Azores and Stykkisholmur/Reykjavik, Iceland since 1865.

SHL8. Clam and Oyster Spatfall

a. Monitoring Objectives

The objective of this supporting variable is to track the yearly spatfall of clams in Hampton Harbor and oysters in Great Bay. This information will be used to help interpret changes in other indicators of shellfish density or standing stock, and will help to answer the following monitoring question:

- "Are NH shellfish healthy, growing, and reproducing at sustainable levels?"

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

For oysters, spatfall is measured by the density of oysters less than or equal to 20 mm shell height during the fall season. For clams, the spat size class has typically been the 1-25 mm shell length. The average spat density at each major clam flat and oyster bed will be tracked versus time. No statistical tests will be applied.

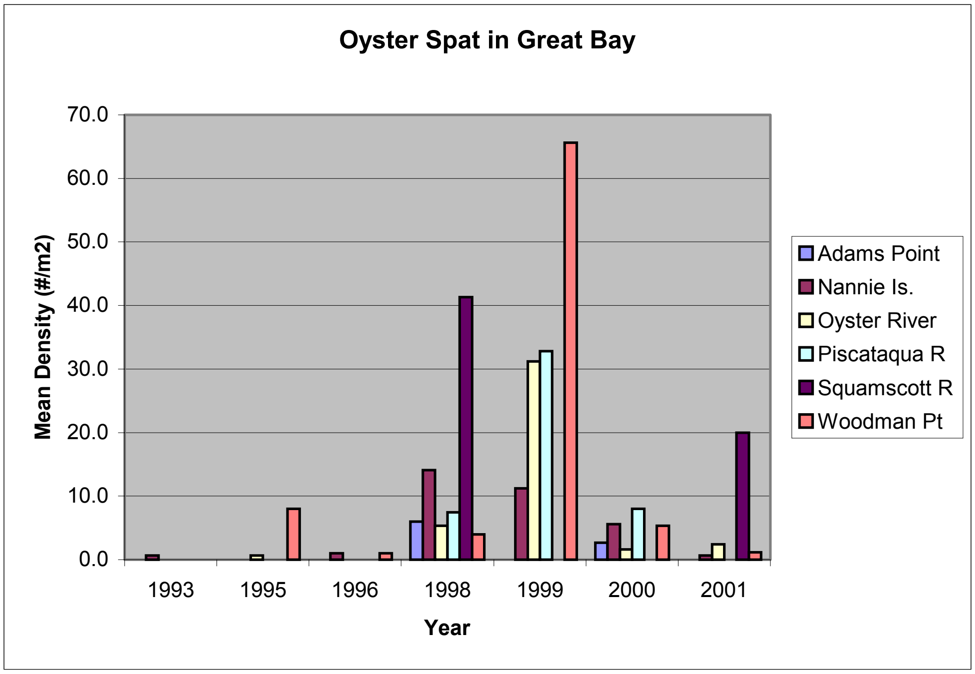
d. Results

Oyster Spatfall

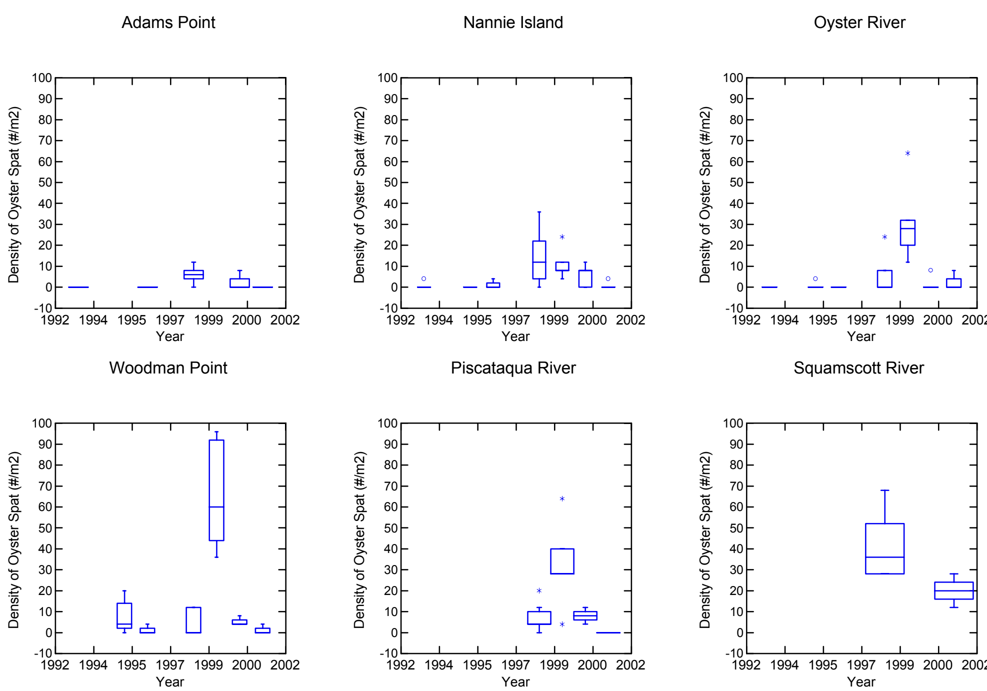
The following table and figures illustrate that the last major spat set in Great Bay oyster beds was in 1998-1999. Spatfall in the last two years has been low in all beds except the Squamscott River bed.

Arithmetic mean density of spat (≤20mm shell height) at Great Bay oyster beds (#/m2)

Year	Adams Point	Nannie Island	Oyster River	Piscataqua River	Squamscott River	Woodman Point	Source
1993	0.0	0.7	0.0				NHF&G
1995		0.0	0.7			8.0	NHF&G
1996	0.0	1.0	0.0			1.0	NHF&G
1998	6.0	14.1	5.3	7.4	41.3	4.0	NHF&G
1999		11.2	31.2	32.8		65.6	NHF&G
2000	2.7	5.6	1.6	8.0		5.3	NHF&G
2001	0.0	0.7	2.4	0.0	20.0	1.1	NHF&G



The following figure illustrates the variance in spatfall between quadrats taken at each bed.



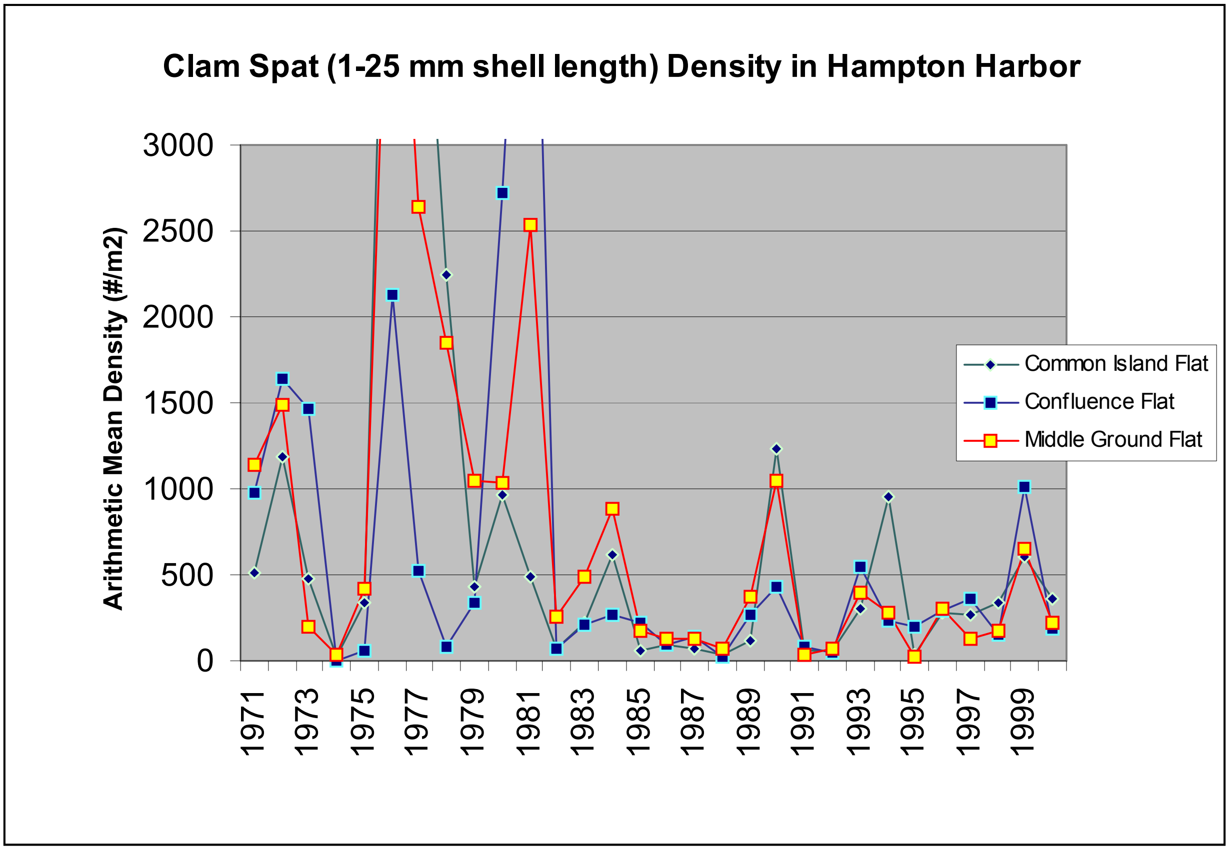
Note: To read this box plot, the bottom, middle, and top of the box indicate the 25th, 50th, and 75th percentiles, respectively. The lines extending from the box reach as far as the 5th and 95th percentiles. Points outside the box and lines are outlier values.

Clam Spatfall

The following table and figure illustrate that spatfall has fluctuated on approximately four year intervals over the past 30 years. Very large spatfalls occurred in the late 1970s and early 1980s.

Arithmetic Mean Clam Spat Densities in Hampton Harbor (#/m2)

Year	Common Island Flat	Confluence Flat	Middle Ground Flat	Source
1971	516.7	979.5	1140.9	Seabrook Station
1972	1184.0	1636.1	1485.4	Seabrook Station
1973	473.6	1463.9	193.7	Seabrook Station
1974	21.5	0.0	32.3	Seabrook Station
1975	333.7	53.8	419.8	Seabrook Station
1976	6242.9	2131.2	5112.7	Seabrook Station
1977	4703.7	527.4	2637.1	Seabrook Station
1978	2249.6	86.1	1851.3	Seabrook Station
1979	430.5	333.7	1044.1	Seabrook Station
1980	968.7	2723.2	1033.3	Seabrook Station
1981	484.4	5586.3	2540.2	Seabrook Station
1982	64.6	75.3	258.3	Seabrook Station
1983	226.0	204.5	484.4	Seabrook Station
1984	613.5	269.1	882.6	Seabrook Station
1985	53.8	226.0	172.2	Seabrook Station
1986	96.9	96.9	129.2	Seabrook Station
1987	75.3	139.9	129.2	Seabrook Station
1988	32.3	21.5	64.6	Seabrook Station
1989	118.4	269.1	376.7	Seabrook Station
1990	1227.0	430.5	1044.0	Seabrook Station
1991	62.1	85.7	38.3	Seabrook Station
1992	58.6	41.1	69.8	Seabrook Station
1993	297.9	542.0	392.1	Seabrook Station
1994	956.4	235.4	275.1	Seabrook Station
1995	36.1	200.4	24.6	Seabrook Station
1996	279.5	289.0	303.8	Seabrook Station
1997	266.9	359.3	123.2	Seabrook Station
1998	336.4	152.8	170.5	Seabrook Station
1999	604.6	1015.9	654.5	Seabrook Station
2000	361.9	188.2	220.2	Seabrook Station


Clam Spat (1-25 mm shell length) Density in Hampton Harbor
Arithmetic Mean Density (#/m2)
3000
2500
2000
1500
1000
500
0
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Common Island Flat
Confluence Flat
Middle Ground Flat

SHL9. Recreational Harvest of Oysters

a. Monitoring Objectives

The objective of this supporting variable is to estimate how many oysters are harvested by recreational harvesters each year (Great Bay is not a commercial oyster fishery). This information is needed to answer the following monitoring question:

- “Are NH shellfish being harvested at sustainable levels?”

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

The total number of oysters harvested yearly will be estimated for the entire Great Bay Estuary. The harvest will be tracked over time and compared to the annual estimate to standing stock. No statistical tests will be applied to these data.

d. Results

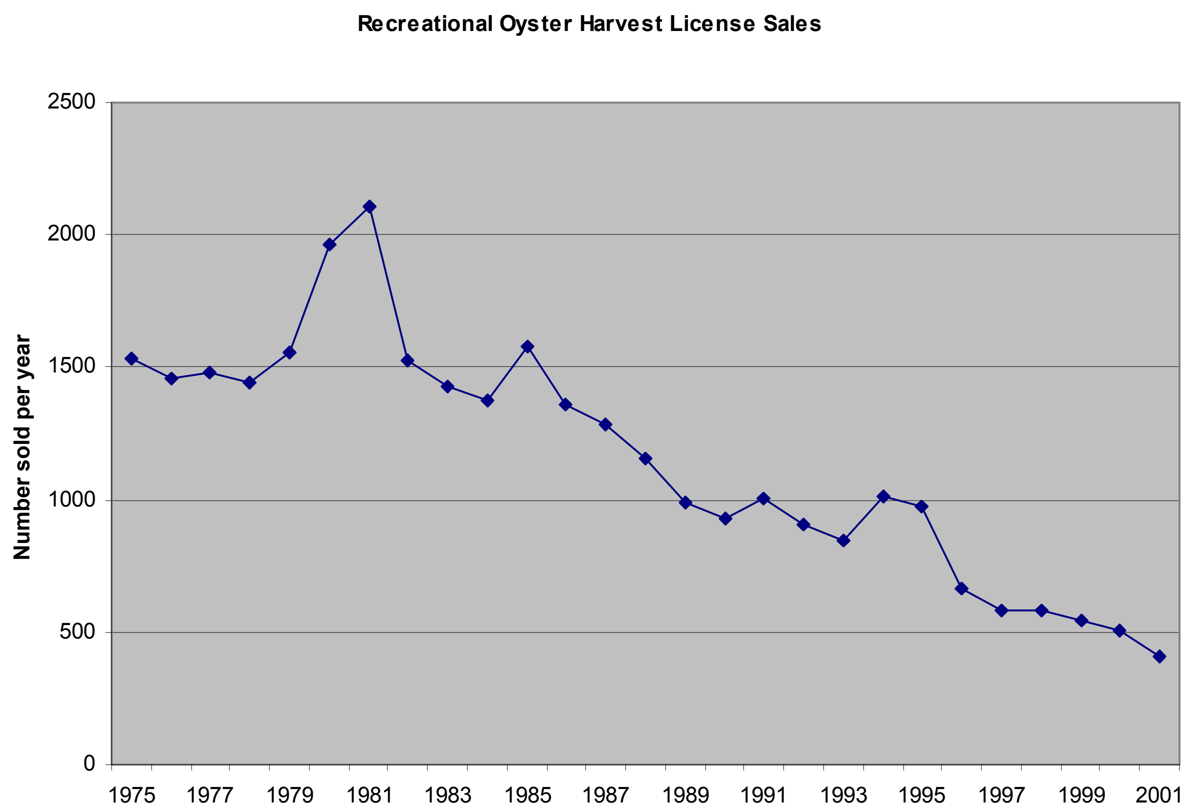
In the following table, the historical record of recreational harvest license sales was combined with the available estimates of oyster harvest. For the years when estimates of oyster harvest were made, the results have been compared to oyster standing stock estimates from indicator SHL-5.

The data indicate a progressive decline in license sales and a proportional decline in total harvest. In 1996, the total harvest amounted to approximately 5% of the standing stock. Based on this comparison, the current levels of harvest appear to be sustainable.

Recreational Oyster Harvest – License Sales and Harvest Estimates

Year	License Sales*	Harvest (bu)	Standing Stock (bu)	Sources	Comments
1975	1532			NHF&G	
1976	1460			NHF&G	
1977	1479			NHF&G	
1978	1440			NHF&G	
1979	1553			NHF&G	
1980	1961			NHF&G	
1981	2109			NHF&G	
1982	1522			NHF&G	
1983	1426			NHF&G	
1984	1373			NHF&G	
1985	1582			NHF&G	
1986	1358			NHF&G	
1987	1285			NHF&G	
1988	1157			NHF&G	
1989	992	>4,000	66,443	NHF&G, Manalo et al, 1991	Using earliest standing stock estimate (1993) from indicator SHL-5 to represent the "late 1980's"
1990	932			NHF&G	
1991	1001			NHF&G	
1992	907			NHF&G	
1993	847			NHF&G	
1994	1009			NHF&G	
1995	971			NHF&G	
1996	661	2,727	54,049	NHF&G, NHF&G 1997	Using standing stock estimate for 1996 from indicator SHL-5
1997	582			NHF&G	
1998	579			NHF&G	
1999	545			NHF&G	
2000	506			NHF&G	
2001	406			NHF&G	

* Oyster harvest license sales total provided by Sue Martin at NHF&G


Recreational Oyster Harvest License Sales
Number sold per year
2500
2000
1500
1000
500
0
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001

SHL10. Recreational Harvest of Clams

a. Monitoring Objectives

The objective of this supporting variable is to estimate how many clams are harvested from Hampton Harbor flats by recreational harvesters each year (Hampton Harbor is not a commercial clam fishery). This information is needed to answer the following monitoring question:

- “Are NH shellfish being harvested at sustainable levels?”

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

The total number of clams harvested yearly will be estimated for the Hampton Harbor flats based on the number of harvesters observed and estimated by the Seabrook Station monitoring program during the clamming season. Assuming that each harvester takes his limit (10 liquid quarts per person per day), the total harvest for the day can be estimated. The daily harvests are totaled to estimate the yearly harvest. The annual harvest will be tracked over time and compared to annual estimates of standing stock. The number of recreational clam harvest licenses sold state-wide is provided by NHF&G. No statistical tests will be applied to these data.

d. Results

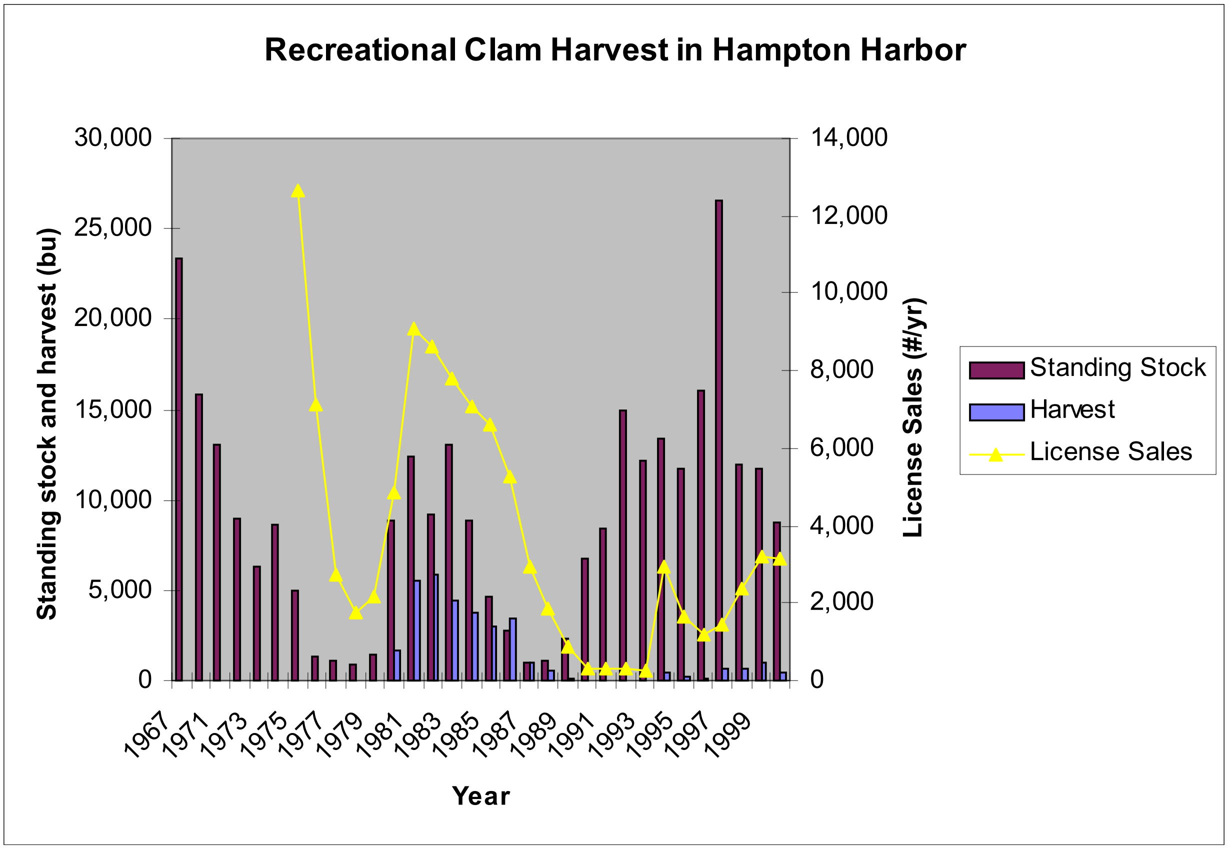
In the following table, data from Seabrook Station and NHF&G have been compiled for the past 25 years. The data show that harvests during the 1980’s were a high percentage of the standing stock before the fishery crashed in the late 1980s. Harvests were zero during the early 1990’s because the flats were closed. Following the re-opening of the flats, harvests have increased but have remained low, presumably because the flats are often closed due to high bacteria concentrations. Both the harvest and standing stock values are estimates, and the error in these estimates is well illustrated by the data for 1987 which shows a harvest value greater than the standing stock value.

License sales provide a slightly longer record back to 1975. While license sales are not directly related to harvest in Hampton Harbor, license sales correlate well with the harvest estimates by Seabrook Station. These data provide an indication that harvest pressure was high preceding the other documented crash of the fishery in the late 1970’s.

Clam Harvest from Hampton Harbor

Year	Estimated Harvest (bu)				License Sales*	Sources
	Common Island	Confluence Flat	Middle Ground	Total		
1975					12,681	Seabrook Station, NHF&G
1976					7,128	Seabrook Station, NHF&G
1977					2,735	Seabrook Station, NHF&G
1978					1,773	Seabrook Station, NHF&G
1979					2,164	Seabrook Station, NHF&G
1980	246	371	1,098	1,715	4,837	Seabrook Station, NHF&G
1981	686	894	3,982	5,561	9,118	Seabrook Station, NHF&G
1982	1,198	686	4,029	5,913	8,648	Seabrook Station, NHF&G
1983	1,353	478	2,554	4,385	7,824	Seabrook Station, NHF&G
1984	920	1,040	1,757	3,716	7,056	Seabrook Station, NHF&G
1985	1,686	290	1,066	3,041	6,616	Seabrook Station, NHF&G
1986	2,006	218	1,159	3,384	5,283	Seabrook Station, NHF&G
1987	404	78	510	992	2,920	Seabrook Station, NHF&G
1988	122	73	368	563	1,881	Seabrook Station, NHF&G
1989	25	12	73	109	904	Seabrook Station, NHF&G
1990	0	0	0	0	286	Seabrook Station, NHF&G
1991	0	0	0	0	318	Seabrook Station, NHF&G
1992	0	0	0	0	287	Seabrook Station, NHF&G
1993	0	0	0	0	248	Seabrook Station, NHF&G
1994	470	0	0	470	2,940	Seabrook Station, NHF&G
1995	232	0	0	232	1,652	Seabrook Station, NHF&G
1996	11	143	0	153	1,183	Seabrook Station, NHF&G
1997	106	602	0	708	1,433	Seabrook Station, NHF&G
1998	471	133	55	659	2,355	Seabrook Station, NHF&G
1999	498	194	330	1,022	3,217	Seabrook Station, NHF&G
2000	348	13	33	394	3,144	Seabrook Station, NHF&G

* Clam harvest license sales total provided by Sue Martin at NHF&G


Recreational Clam Harvest in Hampton Harbor
Standing stock and harvest (bu)
30,000
25,000
20,000
15,000
10,000
5,000
0
License Sales (#/yr)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1967
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Year
Standing Stock
Harvest
License Sales

SHL11. Prevalence of Oyster Disease

a. Monitoring Objectives

The objective of this supporting variable is to estimate the prevalence of the oyster diseases, MSX and DERMO. This information is needed to answer the following monitoring question:

- "Has the incidence of shellfish diseases changed significantly over time?"

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

For each oyster bed, the percent of oysters infected with MSX or DERMO will be reported and tracked over time. No statistical tests will be applied.

d. Results

MSX

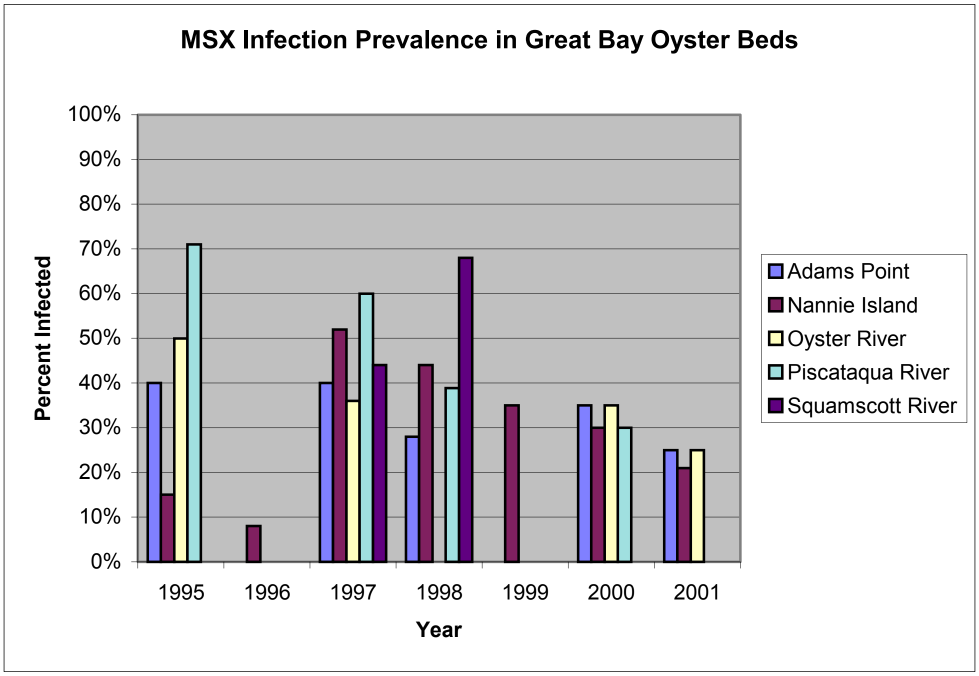
The disease MSX was first detected in Delaware Bay in 1957 and since then has spread throughout the Atlantic coast. The protozoa that causes MSX (*Haplosporidium nelsoni*) is mainly controlled by salinity. The protozoa cannot survive in low salinity water (<10 ppt), has limited virulence at salinities between 10 and 20 ppt, and is fully infectious at salinities >20 ppt (Haskin and Ford, 1982). Therefore, droughts tend to increase the prevalence of MSX infections and allow for expansion of the protozoa's range.

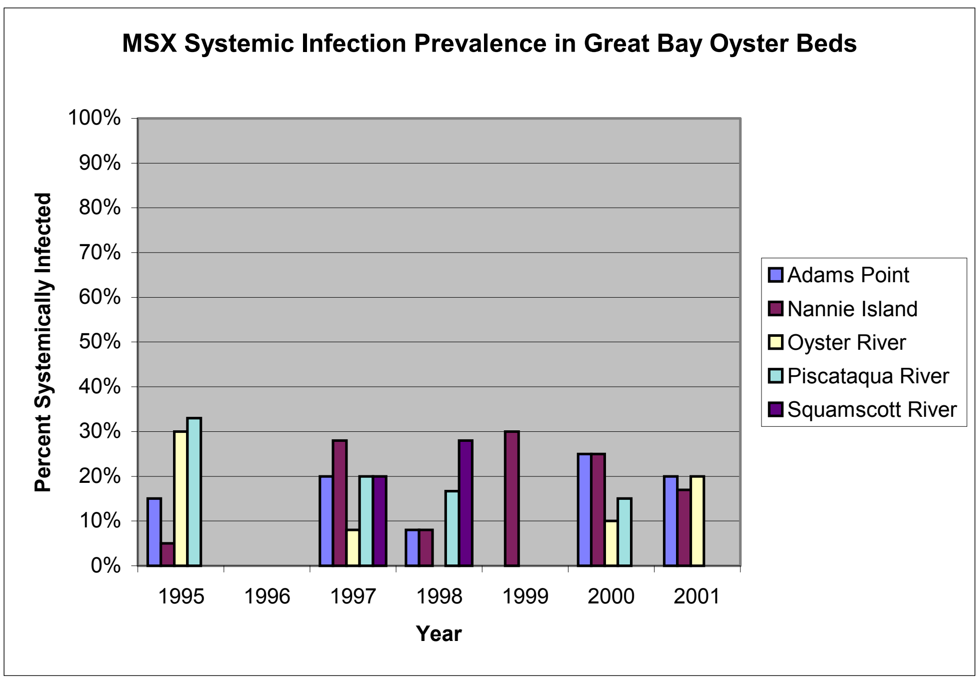
Unspeciated haplosporidian plasmodia were observed in the Piscataqua River as early as 1979 by Maine DMR. MSX was first conclusively determined in the Great Bay in 1983. However the first oyster mortality from the disease was observed in 1995 following a severe drought (Barber et al., 1997).

No significant change has occurred since the disease was first detected in Great Bay in 1995 (the trend at Nannie Island was tested by the Mann-Kendall Test with $p<0.05$). Twenty to forty percent of the oysters in Great Bay are currently infected.

Prevalence of MSX Infection in Great Bay Oysters

Year	Location	Number Tested	Percent Infected	Percent with Systemic Infection	Source
1995	Nannie Island	20	15%	5%	NHF&G, Barber et al., 1997
1996	Nannie Island	40	8%	0%	NHF&G
1997	Nannie Island	25	52%	28%	NHF&G
1998	Nannie Island	25	44%	8%	NHF&G
1999	Nannie Island	20	35%	30%	NHF&G
2000	Nannie Island	20	30%	25%	NHF&G
2001	Nannie Island	24	21%	17%	NHF&G
1995	Oyster River	20	50%	30%	NHF&G, Barber et al., 1997
1997	Oyster River	25	36%	8%	NHF&G
2000	Oyster River	20	35%	10%	NHF&G
2001	Oyster River	20	25%	20%	NHF&G
1995	Adams Point	20	40%	15%	NHF&G, Barber et al., 1997
1996	Adams Point	10	0%	0%	NHF&G
1997	Adams Point	25	40%	20%	NHF&G
1998	Adams Point	25	28%	8%	NHF&G
2000	Adams Point	20	35%	25%	NHF&G
2001	Adams Point	20	25%	20%	NHF&G
1995	Piscataqua River	45	71%	33%	NHF&G, Barber et al., 1997
1997	Piscataqua River	25	60%	20%	NHF&G
1998	Piscataqua River	18	39%	17%	NHF&G
2000	Piscataqua River	20	30%	15%	NHF&G
1997	Squamscott River	25	44%	20%	NHF&G
1998	Squamscott River	25	68%	28%	NHF&G


MSX Infection Prevalence in Great Bay Oyster Beds
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Infected
1995
1996
1997
1998
1999
2000
2001
Year
Adams Point
Nannie Island
Oyster River
Piscataqua River
Squamscott River

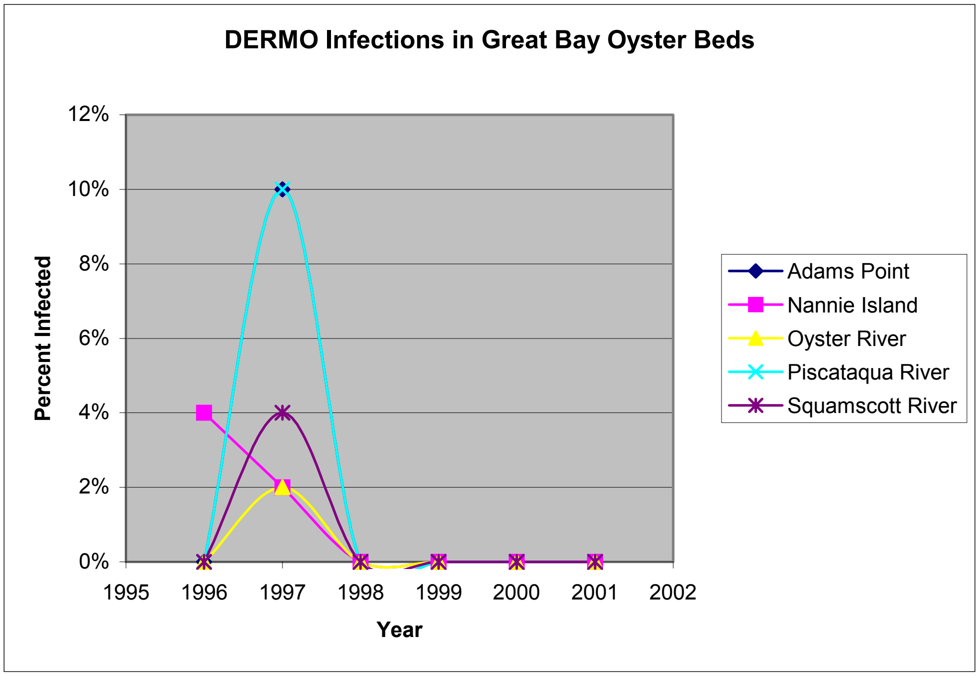

MSX Systemic Infection Prevalence in Great Bay Oyster Beds
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Systemically Infected
1995
1996
1997
1998
1999
2000
2001
Year
Adams Point
Nannie Island
Oyster River
Piscataqua River
Squamscott River

DERMO

The other major oyster disease present in Great Bay is DERMO which is caused by the protozoa *Perkinsus marinus*. However, the infection of Great Bay oysters by DERMO has been less severe than MSX. In 1997, only 10% of oysters from any bed were infected with the disease. DERMO has not been found in NH waters since 1997 except at the Salmon Falls River bed (not shown). It is believed that the colder water temperatures in Great Bay limit the virulence of this parasite in NH waters (NHF&G, 2002).

Prevalence of DERMO Infection in Great Bay Oysters

Year	Location	No. Tested	Percent Infected	Percent Heavily Infected	Source
1996	Nannie Island	25	4%	0%	NHF&G
1997	Nannie Island	50	2%	0%	NHF&G
1998	Nannie Island	25	0%	0%	NHF&G
1999	Nannie Island	20	0%	0%	NHF&G
2000	Nannie Island	20	0%	0%	NHF&G
2001	Nannie Island	25	0%	0%	NHF&G
1997	Oyster River	50	2%	0%	NHF&G
2000	Oyster River	20	0%	0%	NHF&G
2001	Oyster River	20	0%	0%	NHF&G
1997	Adams Point	50	10%	0%	NHF&G
1998	Adams Point	25	0%	0%	NHF&G
2000	Adams Point	20	0%	0%	NHF&G
2001	Adams Point	20	0%	0%	NHF&G
1997	Piscataqua River	50	10%	2%	NHF&G
1998	Piscataqua River	18	0%	0%	NHF&G
2000	Piscataqua River	20	0%	0%	NHF&G
1997	Squamscott River	25	4%	0%	NHF&G
1998	Squamscott River	25	0%	0%	NHF&G


DERMO Infections in Great Bay Oyster Beds
12%
10%
8%
6%
4%
2%
0%
Percent Infected
1995
1996
1997
1998
1999
2000
2001
2002
Year
Adams Point
Nannie Island
Oyster River
Piscataqua River
Squamscott River

SHL12. Prevalence of Clam Disease

a. Monitoring Objectives

The objective of this supporting variable is to estimate the prevalence of clam disease (sarcomastic neoplasia). This information is needed to answer the following monitoring question:

- "Has the incidence of shellfish diseases changed significantly over time?"

b. Measurable Goal

This is a supporting variable so no measurable goal has been established. These data will be collected to provide additional information to help interpret the results of other indicators.

c. Data Analysis and Statistical Methods

Clams are considered neoplastic if 100% of the assayed blood cells are neoplastic. Therefore, for each clam flat, the prevalance of clams with 100% neoplastic cells will be reported. This prevalence will be tracked over time. No statistical tests will be applied.

d. Results

Sarcomatous neoplasia (neoplasia) is a lethal form of leukemia in soft-shell clams. In 1986-1987, neoplasia was first discovered in clams from Hampton Harbor. The incidence of neoplasia in clams from flats 1, 2, and 4 were 6%, 27%, and 0% respectively. By 1989, 80% of the clams from flat 2 had neoplastic cells. In 1996 and 1997, 100% of the clams collected from each flat had neoplastic cells (NAESCO, 1998).

In 1999, the screening process was changed. Instead of reporting the percentage of clams with neoplastic cells, Seabrook Station began reporting the percentage of clams where 100% of the cells were neoplastic. The last survey conducted in July 1999 indicated that the percentage of clams with 100% neoplastic cells ranged from 2.4% to 7.0% at all flats except Middle Ground where no clams with 100% neoplastic cells were detected. It is expected that all of the clams with 100% neoplastic cells will die, leading to a mortality rate of up to 7% (NAESCO, 2001).

Some recent anecdotal information on neoplasia prevalence is available from a NHEP-funded project to study the factors leading to juvenile clam mortality in Hampton Harbor. Among other tests, two sets of juvenile clams from the flats were tested for neoplasia in March and July 2002. Neither set of clams tested positive for neoplasia (Beal 2002). However, the clams tested for this study were juvenile clams from specific areas of the flats and so do not constitute a harbor-wide survey.

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